Application for
UNITED STATES LETTERS PATENT

Of

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and

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For

SKEW COMPENSATION METHOD

TITLE OF THE INVENTION

SKEW COMPENSATION METHOD

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to a skew compensation method and a skew compensation apparatus for automatically compensating for skew occurring among a plurality of serial transmission paths used for high-speed signal transmission with parallel-to-serial conversion.

(2) Description of the Related Art

Parallel-to-serial transmission is a technology which serializes a parallel signal by time division multiplexing, transmits the resultant serial signal, and then parallelizes the serial signal again at a receiver. The technology allows the elimination of the problem of bit-to-bit skew which is conspicuous when the rate of parallel transmission is increased. To implement parallel-to-serial transmission in a broader band, it is necessary to increase the rate of serial transmission, but the acceleration of serial transmission is limited. For broader-band parallel-to-serial transmission, therefore, an approach of using a

plurality of serial signals in parallel has been proposed. However, the approach entails the occurrence of skew between the serial signals, similarly to the parallel transmission.

It is inherently possible to suppress the skew by installing each of the plurality of transmission paths over an equal distance. Due to reduced margin resulting from higher-speed signal transmission, however, it is difficult to install all the lines for serial signals such that they have equal lengths. In particular, tremendous skew occurs in proportion to a transmission distance in the case of WDM (Wavelength Division Multiplexing) used for optical communication. In the WDM, a plurality of serial signals are transmitted in parallel by utilizing the property of a single optical fiber which carries a plurality of optical signals with different wavelengths. In this case, however, the different wavelengths cause tremendous skew irrespective of equal transmission distances.

Japanese Unexamined Patent Publication No. 2000-341135 discloses a technology which transmits a test pattern in equiphase from each of the transmitters for serial signals to eliminate skew occurring among a plurality of serial signal

transmission paths. In accordance with the invention disclosed in the precedent document, each of receivers sends the timing of a synchronization signal to a controller. The controller sets the delay line of the transmitter with the most delayed one of the received timings and thereby matches the reception timings at the receivers.

However, since the foregoing method sends a test pattern by switching normal data to the test pattern, the skew cannot be monitored during the transmission of the normal data so that a sudden skew shift is beyond handling.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a skew compensation apparatus and a skew compensation method which constantly monitor skew occurring during the transmission of a plurality of serial signals, such as the high-speed serial-to-parallel transmission mentioned above, and automatically compensate for the skew, thereby handling the skew among transmission paths and a sudden skew shift.

According to the present invention, a path through which a received signal passes is divided

into two branch signal paths, of which one is connected to a delay controller for monitoring the state of skew and the other is connected to a delay buffer for delaying the received signal by a delay time determined by an amount of skew. The delay controller monitors the state of skew and, if a change occurs in the state of skew being monitored thereby, calculates the delay time for the received signal based on the change in the amount of skew. The calculated delay time is transmitted to the delay buffer which temporally delays the received signal, whereby the amount of skew is adjusted.

In order to perform constant monitoring, the present invention constitutes a skew pattern by using a character stream in which an idle pattern can be inserted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view showing skew compensation patterns and phase shifts at the time of signal reception;

FIG. 2 is a view showing a first embodiment of the present invention;

FIG. 3 is a view showing a compensation pattern generator and a compensation pattern inserter;

FIG. 4 is a view showing a delay controller and a delay buffer;

FIG. 5 is a view illustrating a method for demultiplexing a parallel data stream into a plurality of lanes;

FIG. 6 is a view showing parallel data outputted from a transmitter;

FIG. 7 is a view showing parallel data received by a receiver;

FIG. 8 is a view showing parallel data including valid data which is outputted from the transmitter;

FIG. 9 is a view showing parallel data including valid data which is received by the receiver; and

FIG. 10 is a view showing a second embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[EMBODIMENT 1]

A first embodiment of the present invention will be described herein below with reference to the drawings. Although specific numerical values are used in the following description for the sake of clarity, they are only exemplary and the present invention is by no means limited to these values.

The present invention is characterized in that

skew compensation patterns shown in FIG. 1 are prepared and skew compensation is performed by transmitting the skew compensation patterns from a serial data transmitter and measuring the amount of the skew at a receiver.

Referring to FIG. 2, a description will be given first to the overall structure of an apparatus.

A parallel signal transmission apparatus having a skew compensating function according to the present invention is constituted by a transmitter 1 and a receiver 3. The transmitter 1 inserts a skew compensation pattern in a data stream of a parallel signal, converts the parallel signal to a plurality of serial signals, and outputs the plurality of serial signals. A transmission line unit performs wavelength multiplexing with respect to the plurality of serial signals received from the transmitter 1, transmits the serial signals over a long distance by using a single optical fiber, and outputs the serial signals after performing wavelength demultiplexing again on the received signals.

The receiver 3 parallelizes the plurality of serial signals received from the transmission line unit. At this time, the plurality of serial signals

have skew that has occurred during the transmission. The receiver 3 calculates an amount of skew among the individual transmission lines from the skew compensation pattern inserted by the transmitter 1, inserts delays in the respective transmission paths such that the skew is cancelled out, and thereby establishes the temporal matching property of the parallel signal.

A detailed description will be given next to the structure and operation of each component.

The transmitter 1 is comprised of a parallel signal demultiplexer 10, a compensation pattern generator 12, compensation pattern inserters 14, encoders 16, serializers 18, drivers 20, and a connector 21.

As shown in FIG. 5, a parallel data stream 400 is inputted to the parallel signal demultiplexer 10. In the parallel data stream 400, a bit stream is arranged in the direction indicated by the arrow 401. The bit stream contains data 410 (and 415) in the state of a packet. In the present description, data in the state of a packet is termed "valid data" and unneeded data other than the valid data is termed "invalid data".

In FIG. 5, 403 denotes invalid data and the

hatched portion 405 denotes valid data. The bit stream mentioned above is inputted continuously in a temporal direction to the transmitter 1. The parallel signal demultiplexer 10 demultiplexes the inputted parallel data stream into a plurality of lanes 420 each having a given bit width. If it is assumed that the bit width is 32 bits and the data stream is composed of 128 bits in the present description, the data stream can be demultiplexed into four lanes from a lane 1 (420-1) to a lane 4 (420-4). A data stream in each of the lanes is composed of a header 421, empty data 423, and valid data 425. The header 421 indicates whether the data stream is the valid data 425 or the invalid empty data 423. By demultiplexing the data stream in this mannetr, the data 410 and the data 415 are demultiplexed into the individual lanes to provide the data 430 and the data 435, though synchronization in the temporal direction is retained.

A description will be given next to the skew compensation pattern generated by the compensation pattern generator 12.

The skew compensation pattern has plural types of patterns by combining a plurality of characters, as shown in the table of FIG. 1. A "character" is

defined herein as a character system capable of determining valid data and invalid data and incorporating a control signal indicative of the start and end of an idle or a packet in invalid data, such as, e.g., a 8B/10B character. Each of the "i_0" and "i_1" in the block payloads (hereinafter referred to as the idle character) is a character indicative of an idle state or invalid state in which significant data is not transmitted. By using the idle character, the skew compensation pattern can be inserted as invalid data in a data stream containing valid data and easily separated therefrom.

The transmitter collectively transmits a plurality of idle characters as one character. For example, a "64B/66B" character defined by the IEEE 802.3ae is composed of eight 8B/10B characters transmitted collectively. By using a delimiter (synchronization point) for such characters as a delimiter for the patterns, the patterns can easily be separated from each other.

The present invention determines a required number of patterns in accordance with the following method.

(1) An amount of skew S occurring in the transmission line unit is assumed. For example,

skew of 100 ps occurs on every transmission over a distance of 1 m.

(2) A transmission distance L (e.g., 80 km) is assumed.

(3) A maximum amount of phase P using the number of characters as a measurement unit is determined from the following numerical expression (1) where T is a transmission rate (e.g., 10 Gbit/s) in the transmission line unit and C is a length of a character (e.g., 66 bits):

$$P = T \times S \times L/C \quad \ldots (1)$$

For the transmitter to transmit the pattern as a circulative pattern cycle and for the receiver to measure the amount of skew, the receiver is required to detect the start of each cycle and determine the first reaching lane and the last reaching lane so that at least "2P+1" patterns are necessary. In the case of a system that allows the receiver to reliably predict the start of the pattern, for example, in such a case that the transmitter transmits only one cycle of the pattern after the completion of a set-up at the receiver, "P+1" is sufficient as the number of patterns because the process of detecting the start of the pattern cycle becomes unnecessary.

A description will be given next to an embodiment

of pattern generation.

There is a character having a plurality of idle characters. For example, "K28.0", "K28.3", and "K28.5" are allocated as idle characters to a 8B/10B character. If a skew compensation pattern is formed by using these plurality of idle characters, they are allocated to the individual digits of a number represented in an n-digit number system. If the pattern is formed in a binary system, for example, allocation is performed in such a manner that the characters "i_0" and "i_1" correspond to the binary digits "0" and "1", respectively. If the pattern is formed in a ternary system, for example, the character "i_2" is allocated to the digit "2". The pattern represented as "1010" in the binary system can be converted to the pattern "i_1, i_0, i_1, i_0" and reverse conversion is also possible. Since the pattern represented as "1010" in the binary system corresponds to "12" in a decimal system, the pattern "i_1, i_0, i_1, i_0" is abbreviated as "I_{12}" in the embodiment of the present invention.

The compensation pattern generator 12 has the structure shown in FIG. 3 and is composed of a counter 120 and an encoder 125. A value generated in the counter 120 is a numerical value which circulates

around the number of patterns. In the case of sixteen patterns shown in FIG. 1, the values "0, 1, 2, ... 14, 15, 0, 1, ..." are outputted. The encoder 125 generates a skew compensation pattern based on the values in accordance with the foregoing method. Consequently, the pattern generated from the compensation pattern generator 12 becomes circulative and, if the total of sixteen patterns shown in FIG. 1 are provided, e.g., such a circulative pattern as "I_0, I_1, I_2, ... I_{14}, I_{15}, I_0, I_1, I_2, ..." is obtained.

A one-lane parallel signal outputted from the parallel signal demultiplexer 10 and a skew compensation pattern generated from the compensation pattern generator 12 are inputted to the compensation pattern inserter 14. The compensation pattern inserter 14 has the structure shown in detail in FIG. 3 and is composed of a selector 140 and a valid data discriminator 145.

The selector 140 selectively outputs one of the inputted parallel signal and the inputted skew compensation pattern. The selector 140 is controlled by the valid data discriminator 145. The valid data discriminator 145 discriminates valid data in the inputted parallel signal and controls

the selector 140 such that the parallel signal is selectively outputted when the parallel signal is valid data and the skew compensation pattern is selectively outputted when the parallel signal is invalid data.

The encoder 16 receives the parallel signal from the compensation pattern inserter 14 and converts the data to characters for transmission. The parallel signals are converted into a serial signal in the serializer 18 and the serial signal is converted from an electric signal to an optical signal in each of the plurality of drivers 20-1 to 20-n so that the optical signal is outputted through the connector 21. The connector 21 forms the terminating portion of the transmitter 1 and is connected to the optical signal multiplexer 23 by a connector 22. Although the multiplexer 23 disclosed in the present embodiment is used as an external attachment part, the multiplexer 23 may also be contained in the transmitter 1.

The plurality of optical signals outputted from the transmitter 1 pass through the connector 22 and wavelength-multiplexed by the multiplexer 23. The optical signal is transmitted to a demultiplexer 25 through a single optical fiber 24. The

demultiplexer 25 wavelength-demultiplexes the received optical signals. The optical signals that have been wavelength-demultiplexed is outputted to the receiver 3 through a connector 26.

The recover 3 is comprised of a connector 27, receiver elements 28, de-serializers 30, decoders 32, signal demultiplexers 33, a delay controller 34, delay buffers 36, and a parallel signal multiplexer 38. The serial signals carried through the transmission line unit pass through the connector 27 and are converted from the optical signals into electric signals by a plurality of receiver elements 28-1 to 28-n. After that, each of the electrical signals is converted from the serial data to parallel data by the de-serializer 30. The decoder 32 receives the parallel data, recognizes the transmitted characters, and decodes the transmitted characters.

The parallel data outputted from a plurality of decoders 32-1 to 32-n are copied in the signal demultiplexers 33-1 to 33-n and then supplied to a plurality of corresponding delay buffers 36-1 to 36-n and to the delay controller 34. The delay controller 34 and the delay buffer 36 will be described in detail with reference to FIG. 4.

The delay controller 34 is comprised of a plurality of decoders 340-1 to 340-n, a skew amount calculator 343, a counter 346, and a register 349. The decoder 340 has the function of extracting a block payload (e.g., "i_1, i_0, i_1, i_0") consisting of the idle characters from the inputted parallel data and converting the extracted block payload to a phase value (e.g., "12") by using the table of FIG. 1. The counter 346 generates a count value (the receiver internal timing) which circulates around the number of patterns, similarly to the counter 120 of the transmitter 2. The skew amount calculator 343 calculates amounts of skew corresponding to the individual lanes from the phase value received from the plurality of decoders 343 and the count value received from the counter 346. The amounts of skew are held in the register 349 and presented as the current amounts of skew to the delay buffers 36.

Each of the delay buffers 36 is comprised of a shift register 360 and a selector 365. The parallel data inputted to the delay buffer 36 is sent first to the shift register 360. The shift register 360 shifts the inputted data on a per clock basis and outputs the data to the selector 365. The selector 365 reads out the data from the shift register 360

at the position at which the amount of skew presented by the register 349 is cancelled out and outputs the data.

The above circuit structure establishes a state in equiphase with no skew among the individual lanes, which is similar to that observed during transmission. The parallel signal multiplexer 38 multiplexes the parallel data in equiphase received from the plurality of delay buffers 36-1 to 36-n, and outputs the recovered original parallel data stream.

A description will be given next to a method for calculating the amount of skew in the skew amount calculator 343.

As shown in FIG. 6, parallel data 510-1 to 510-n and transmitter internal timings 500 generated by the counter 120 are in synchronization with each other and all in equiphase. At a timing 550 indicative of T = 0 among the transmitter internal timings 500, parallel data 520-1 to 510-n in the respective lanes 510-1 to 510-n indicate the same pattern "I_0".

FIG. 7 shows the state of the parallel data received by the receiver 3 via the transmission line unit. Although the phases are equal in the individual lanes at the time of transmission,

received patterns are different in individual lanes 610-1 to 610-n at the time of reception since temporal delays depending on individual paths are included. At a timing 650 indicative of T = 0 among receiver internal timings 600, for example, a pattern 620-1 in the lane 1 (610-1) is "I_{15}", a pattern 620-2 in the lane 2 (610-2) is "I_{12}", and a pattern 620-n in the lane n (610-n) is "I_2". The skew amount calculator 343 receives a value obtained by decoding the pattern in each of the lanes, for example, "12" is received in the case of "I_{12}".

The skew amount calculator 343 determines differential values between the values obtained by decoding the patterns in the individual lanes and the receiver internal timings generated by the counter 346 and stores the differential values in the register 349. The differential values indicate skew values in the individual lanes and serve as positions at which data is read out from a shift register 360 in the delay buffer 36.

[EMBODIMENT 2]

In contrast to the first embodiment in which the transmission line unit transmits the plurality of optical signals by using the WDM method, a second embodiment according to the present invention is

characterized by the transmission of a plurality of optical signals using a parallel fiber obtained by bundling a plurality of optical fibers.

FIG. 10 shows the structure of an apparatus according to the second embodiment by retaining the same reference numerals for the same components as used in the first embodiment.

In the transmission line unit, a plurality of optical signals outputted from transmitter 1 are sent out to a parallel fiber 40 through the connector 41. The parallel fiber 40 transmits the plurality of optical signals outputted from the drivers 20-1 to 20-n in parallel by using a single optical fiber as a transmission path for each of the optical signals. These optical signals are inputted to the receiver 3 through the connector 42. A plurality of optical signal input ports are provided between the connectors 21 and 40, though they are not depicted.

[EMBODIMENT 3]

In the first embodiment, the skew amount calculator 343 determines the differential values between the values obtained by decoding the patterns in the individual lanes and the receiver internal timings generated by the counter 346 and stores the differential values in the register 349. By

contrast, the third embodiment reads out the patterns in invalid data even when valid data is included in the parallel data in the individual lanes and determines the differential values between the patterns and the receiver internal timings in the same manner as in the first embodiment. In addition, the third embodiment compares the differential values with the differential values stored in the register 349 and judges that the current state is normal if the differential values are the same and that the skew has suddenly shifted if the differential values are different. In the event of a skew shift, the differential values are overwritten in the register 349 for skew compensation.

As shown in FIG. 8, if the inputted parallel data are data packets or the like in a network apparatus, they are transmitted with valid data 570 and 575 enveloped therein. Between the valid data 570 and 575, there is invalid data included. However, the probability that the receiver receives the invalid data in all the lanes at the receiver internal timings is low, as shown in FIG. 9. Then, the third embodiment independently operates the individual lanes so that the lane that has received the skew compensation pattern included as the invalid data

performs the skew compensation, while the lane that has not received the skew compensation pattern is placed on standby until it receives the next skew compensation pattern. This method enables skew compensation even if all the lanes do not receive the skew compensation pattern at the same time.

Thus, the present invention constantly monitors skew occurring when a plurality of serial signals are transmitted by high-speed serial-to-parallel transmission and automatically compensates for the skew, thereby handling skew among transmission paths and a sudden skew shift.